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ENERGY LOSSES TO SURFACE PLASMONS BY CHARGED PARTICLES*

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Experimental work reported by Biersack at this Seminar indicates that appreciable energy loss specific to the surface of a stopping medium may occur when a charged particle traverses condensed matter. Some time ago the authors[1] made an estimate of the magnitude of such losses for a surface plasmon model in another connection.

Here we review briefly the theory of charged particle energy loss to the surface plasmon field for a swift charged particle incident on a model metallic system. We estimate the expected energy loss for some representative cases.

To establish the order of magnitude of the surface effect, a schematic model is sufficient. A swift ion with charge Ze crosses the surface of a plane-bounded, semi-infinite electron gas that is characterized by a dispersionless surface plasmon mode with eigenfrequency ω_s. The velocity vector, $\vec{v}$, of the ion makes an angle θ with the surface normal. It is a good approximation[2,3] to write the probability, P_s, of exciting a surface plasmon during the crossing as

$$P_s = \frac{CZe^2}{\hbar v \cos\theta} = \frac{CZe^2}{\hbar v_\perp} \qquad (1)$$

where C is a constant of the order of one and $v_\perp$ is the component of the ion velocity perpendicular to the surface.

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A disturbing aspect of Eq. (1) is that P_s may be greater than 1. This defect is due to the fact that Eq. (1) was derived under the assumption that no depletion of the initial state is allowed. Approximate accounting for this is accomplished by writing[4]

$$P_n^{(s)} = \frac{(P_s)^n}{n!} e^{-P_s}$$

where $P_n^{(s)}$ is the probability of creating n surface plasmons in a crossing of the surface. This Poisson distribution of losses has the property that $\sum_{n=0}^{\infty} P_n^{(s)} = 1$, as it should.

Then the total energy, E_s, lost to the surface plasmon field must be given by

$$E_s = \sum_{n=1}^{\infty} n\hbar\omega_s P_n^{(s)} = \hbar\omega_s P_s = \frac{q Z e^2 \omega_s}{v_\perp}$$

For a 30-keV proton incident on a metallic surface at $\theta = 89.5°$ with the normal, $P_s \sim 10$ and

$$E_s \sim 200 \text{ eV}$$

for a representative value of $\hbar\omega_s = 20$ eV. On the other hand, if a 30-keV proton is incident normally, $P_s \sim 1$ and $E_s = 20$ eV.

Hence, one expects a rather small contribution from surface plasmon creation to the energy loss by ions compared with the losses experienced in the bulk of foils with ordinary thicknesses. For example, a 30-keV proton should lose $\sim$ 12 keV to bulk processes in traversing a carbon foil only 1000 Å thick.

It should be pointed out that the description of surface losses given above will result in an overestimate of their contribution to the energy loss of a charged particle. This is due to the fact that the losses to surface modes described above are partially compensated for by a decrease in loss to bulk modes near the surface.[2] The latter is attributable to orthogonality of the eigenfunction of the surface modes to those of the bulk modes.[4]

References

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